RESEARCH ARTICLE

Development of an Improved Smart Solar Post-harvest Dryer

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ABSTRACT: The most potent way to address the issue of food scarcity as the global population rises is the reduction of food losses. Drying is a major channel of achieving safety and security of food items. In this study, an improved smart solar dryer was developed and its performance was evaluated. 200g of fresh corn and 400g of ripe plantain were used to investigate the performance of the developed dryer. Both products were weighed and placed in the dryer and open sun drying for some days. Moreover, weight losses of the products in the dryer and open sun as well as various temperatures were measured. The results showed that the ambient temperature during the experiments was lower than the temperature of the drying chamber. In this experiment with 200g of fresh corn and 400g of unripe plantain, an overall moisture content of 78% w.b and 76.2% w.b were removed from fresh corn and ripe plantain in the dryer within 7 days. However, 72.4% w.b. and 70.4% w.b. moisture content were removed from fresh corn and ripe plantain placed in open sun drying for 10 days. The efficiency of sun drying was 49.54% for ripe plantain and 25.48% for fresh corn whilst the dryer was 27.45% and 53.67% for fresh corn and ripe plantain respectively. The developed smart solar dryer is economically viable and preferred to be replicated among local farmers in Nigeria so as to protect the environment and saves cost and time spent on open sun drying of farm produce.

KEYWORDS: Smart Solar Dryer, Performance evaluation, drying chamber, temperature, heating chamber.

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1. INTRODUCTION

The global population is projected to increase more than 9 billion by 2050, and this requires increase in food production by about 70% [1]. In the light of this, high growth rates are expected in developing countries like sub-Saharan Africa where there is high level of food scarcity and malnutrition [2]. Improving productivity and decreasing the existing high rates of global food loss and waste, including post-harvest loss, along the various production and supply chains is indispensable in addressing the issue of food insecurity in Sub-Sahara Africa like Nigeria. In the global scale, about 1.3 billion tonnes of food produced for human consumption are lost on a yearly basis [1]. According to Hodges [3], the major factors causing food loss in developed countries occurs at the consumption stage, whereas in developing countries like Nigeria, it occurs in post-harvest handling and processing [4]. Food losses contribute heavily to food scarcity, and this have made large number of people in low-income countries to suffer from malnutrition [1,5,6].

Specifically, inappropriate and inefficient drying practices along the food value chain have resulted to substantial amount of income losses among farmers, food distributors, processors, and exporters in Sub-Sahara African regions. Apart from income losses, poor drying has also contributed to contamination of aflatoxin, an important food safety and public health concern in developing nations. In that case, the utilization of efficient drying technologies have the potential to mitigate post-harvest losses encountered by farmers in developing countries. Drying is usually considered to be an energy-intensive and cost-effective method to improve the storage of different types of agricultural products. During a simultaneous transfer of heat and mass, moisture is evaporated near the surface by several mechanisms such as liquid and vapour diffusion, capillary and gravity flows, and flow due to shrinkage and pressure gradients [7]. A decrease in moisture content prevents the

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growth of micro-organism, reduces many of the moisture inter-mediated, deteriorate reactions such as enzymatic reactions, non-enzymatic browning, and oxidation of lipids and pigments, and substantially reduces weight and volume [8,9].

In industrialized regions, open-air sun drying has now been largely replaced by mechanized dryers. Mechanized drying is faster than open-air sun drying, uses much less land and usually gives a better-quality product. But the equipment is expensive and requires substantial quantities of fuel or electricity to operate.Alternatively, more emphasis is focused on using solar energy sources due to high prices and shortages of fossil fuels. In Nigeria, open-air sun drying is the most common used method of preserving agricultural products due to its affordability, especially for farmers in rural areas. However, the drying process greatly relies on ambient conditions and is very prone to contamination by dust, rain, wind, pests, and rodents [10,11], leading to low-quality products and a loss of farmers' income.

For the past few years, scientist and researchers have been trying to find the solution to overcome the above-mentioned problem. They developed various type solar dryer for drying applications which outcomes showed that drying process is simple, cheaper and products are dried under hygienic environment. Solar drying helps to retain the quality of product by reducing its mass and volume which helps in good packaging of these products for their better mobility. Recently, solar dryers are now becoming popular in Sub-Sahara Africa since they have proved to be better, more energy efficient and contribute in reducing greenhouse gas emissions. This abundantly available solar energy can be used for the drying of agricultural products. Thus, it is necessary and expedient to seek for alternative sources of energy such as solar energy sources due to high prices and finite nature of fossil fuels which may run out in the foreseeable future. In addition, energy from solar is clean and renewable. This makes it an agent for mitigating greenhouse gas emissions in the ecological environment. Therefore, the need to deploy an improved smart solar dryer technology developed for post-harvest processing so as to achieve food security and subsequently reduces carbon foot print in our environment.In this design, the heating chamber receives short wave radiation of heat from the sun and stores the thermal energy with materials of very high specific heat capacity (black coloured granite) when there are no sun rays. Solar powered exhauster fan was in-cooperated and used for efficient removal of moisture in the dryer which help to increase the heat circulation and lower the time for drying. The drier is capable of drying food materials sourced from plants and animals.

MATERIALS AND METHODS

Design Considerations

The dryer was constructed using wood, stainless steel wire mesh, transparent glass, aluminium profile and exhaust fan for operation of the dryer which are locally available with low cost. An indirect type passive solar dryer was considered as it does not affect the colour and nutrient content of the product as in the case with a direct type. Also, the drying is uniform without any localized heating. Transparent glass material was used as a collector as it is a good conductor and economical. The collector has been rigidly fixed to the dryer at an angle of 15.5° to the horizontal to obtain approximately perpendicular beam of sun rays. Granite materials painted black was placed below the glass material in the heating chamber (in the plywood) to increase the absorption of heat [12,13]. The recommended glass thickness for collector is 5 mm whilstair gap of 1 cm is recommended for a tropical climate and these were used. The insulating material was selected to be plywood as it is a good insulator as well as environmentally friendly. It also does not have any carcinogenic effects which other popular insulating materials like glass wool have. Food grade stainless steel wire mesh for the trays was selected for placing of produce. To ensure the constant flow rate of air, an exhaust fan operated by 12volt battery was selected. Solar panel system was deployed to charge the battery during the day when sun rays are available. A small circuit was integrated into the dryer to perform the function of ON and OFF during the day and night hours which makes the dryer a smart one. For the purpose of experimentations, 200g of corn and 400g of plantain which is locally available were used. Figure 1 presents the dryer with and without load.

Operation of improved smart solar dryer

The materials used for the development of the indirect passive solar dryer are cheap and easily obtainable in the local market. The solar dryer

consists of the heating chamber, flexible connector, drying chamber with chimney and supporting stands. The dryer of 495x495x895 mm was designed from aluminium profile, wood and glass materials to help absorb heat from sun rays thereby quickening the drying time. The heating chamber and solar collector were made with glass materials and plywood. This water-resistant wood (plywood) was filled with materials of very high specific heat capacity (granite painted black) to absorb the heat when the dryer was exposed to solar radiation. This granite material retained the heat and gives out gradually when the solar radiation was absent. This heat is of long wavelength and cannot pass through the glass again but finds its way into the drying chamber by convection thereby drying the food materials placed in the drying chamber. The developed dryer was incorporated with small exhaust fan to adequately remove the moisture formed before it condensate at its wall. A small solar panel was added in the dryer to operate the fan. Moreover, a 12V battery was deployed to power the fan during the time when solar radiation was absent. A small circuit was integrated into the dryer to carry out the role of ON and OFF during the day and night hours which make it an automated system. The developed dryer consists of 4 shelves for drying agricultural products. Table 1 shows the Bill of materials used in the fabrication of the drying system.

The following materials were used for the development of an improved smart solar dryer.

1. Wood - This was used to construct the heating chamber and supporting stands. Wood was selected since it is a good insulator and relatively cheaper than metals.
2. Glass – It was used as the solar collector in the heating chamber and for constructing the drying chamber and chimney. It permits the solar radiation into the system but resists the flow of heat energy out of the systems.
3. Aluminium profile – This was used for developing the drying chamber and to increase absorption of solar radiation.
4. Nails and glue - These were used as fasteners and adhesives.
5. Hinges and handle - It was used for constructing the dryer's door
6. Black paint – It was used to paint the granite materials in order to increase its absorptivity.
7. Granite painted black – It was used to absorb and retain the heat when the dryer was exposed to solar radiation.
8. Small exhaust fan – This was used to adequately remove the moisture formed before it condensate at its wall.
9. A small solar panel – It was used to operate the fan.
10. Wire mesh- It was used for constructing the trays for placing the products

Table 1: Bill of Materials

S/N	Component	Material	Dimension (mm)
1	Solar Collector	Glass	1230 x 535
2	Absorber	Granite	5kg
3	Heating Chamber	Wood	1230 x 535x 322
4	Drying Chamber	Glass	495 x 495 x 895
5	Insulation	Wood	1200 x 535 x 322
6	Tray	Stainless Steel	425 x 425
7	Roof base	Wood	505
8	Height	Glass	280
9	Slant	Glass	370

Design Calculations

(i) Insolation on the Collector Surface Area

A research obtained the value of insolation for Uturu i.e. average daily radiation H on horizontal surface asH =1890 W/m^2 and average effective ratio of solar energy on tilted surface to that on the horizontal surface R = 1.0035[14].

Insolation, Ic on the collector surface was obtained as

$I_c = H_T = HR = 1890 \times 1.0035 = 1897\ W/m^2$ (1)

(ii) Angle of tilt of the solar collector/air heater

The angle of tilt (β) of a solar collector is $\beta = 10^{o} + lat\ Ø$ (2) [15]

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Latitude of Gregory University, Uturu where the drying experiment took place was 55°N. Hence, the suitable value of β used for the collector is β = 10° + 5.5 = 15.5°

(iii) Determination of Collector Area and Dimension:

The mass flow rate of air Ma was determined by taking volumetric flow rate. Thus, volumetric flow rate of airV'a was calculated from (average wind speed at Gregory University)

Va = 11km/hr = (11x1000)/(3600) m/s = 3m/s, width of the collector, Wc = 0.535m, and air gap height, A_h = 0.01m

V'a = Va x A_h x Wc (3) [14]

V'a = 3 x 0.01 x 0.535

V'a = 0.01605m^3/s

But mass flow rate of air is given as

Ma = V'a × ρa (4)

Where air density, ρa = 1.28 kg/m^3

Ma = 0.01605 x 1.28

Ma = 0.0205kg/s

Where Cp = 1005 J/kg/K, Ta = 28^{o}C,

To = 60^{o}C

Ac x 0.5 x Ic = Ma x Cp (To - Ta) (5)

$$Ac = \frac{Ma\ x\ Cp\ x\ (To - Ta)}{0.5x\ Ic}$$

Ac x 0.5 x Ic = 0.0205 x 1005 x (60-28)

$$Ac = \frac{0.0205\ x\ 1005\ x\ (60 - 28)}{0.5x\ 1897}$$

$$Ac = \frac{0.0205\ x\ 1005\ x\ (32)}{0.5x\ 1897}$$

Ac = 659.28/948.5

Ac = 0.695m^2

The length of the solar collector (L) was taken as;

L = Ac/Wc = 0.695/0.535 = 1.230 m

Thus, the length of the solar collector was taken approximately as 1.23m.

(iv) Determination of the Base Insulator Thickness for the Collector

The rate of heat loss from air is equal to the rate of heat conduction through the insulation. The following equation holds for the purpose of the design.

$$FMaCp\ (To\text{-}Ta) = \frac{AcKa(To-Ta)}{tb} \quad (6)$$

Where;

Ka = 0.13$Wm^{-1}K^{-1}$ which is the approximate thermal conductivity for Plywood.

T_0 = 60ºC and Ta = 28ºC

Ma = 0.0205kg/s

Cp = 1005 JKg-1K-1

Ac = 0.695m^2

F = 10% = 0.1

$$tb = \frac{AcKa(To-Ta)}{FMaCp(To-Ta)}$$

$$tb = \frac{0.695\ x\ 0.13(60-28)}{0.1\ x\ 0.0205\ x\ 1005(60-28)} = \frac{2.8912}{65.928} = 0.044m = 4.4cm$$

For the design, considering heat loss and heat transfer, the thickness of the insulation was taken as 5 cm.

Figure 1: Smart Solar dryer (with and without drying materials)

Table 2: Project Cost Analysis

Activity/Material	Amount (₦)
Development Cost (C_1)	20,000
Wood materials Cost (C_2)	
Two sheet of Plywood (3/4”)	28,000
12 pieces of 2 by 4 plank	4,800
Glass and aluminium (C_3)	
Glass and cutting	17, 000
Aluminium profile	5,000
Rubber and metallic materials (C_4)	
3 yards of wire mesh and 4kg of nail	2, 000
Door hinges and 10 yards of rubber gasket	1,500
Electric devices (C_5)	
Small fan	1,000
Small solar panel and hanger	4,500
12V battery	2,000
Circuit	2,500
5yards electric wire	500
Paint and Glue (C_6)	
Black paint and glue	1500
Transportation cost (C_7)	
Transporting of materials	5000
Total	95,300

Total Cost (C):

Total cost for the smart solar Dryer = $C_1 + C_2 + C_3 + C_4 + C_5 + C_6 + C_7$ = ₦95,300

Sample Collection and Experimentation

Fresh corn and unripe plantain were purchased at Achara market in Uturu, Abia State, Nigeria. Corn seeds were detached from the cob. The peel was removed from the plantain and the edible part was sliced into smaller sizes. 200g of fresh corn kernels and 400g of unripe plantain were chosen, weighed and then placed in the drying chamber. The weight of the corn and plantain in the developed dryer was measured in the morning, afternoon, evening and night hours with digital weighing balance. Ambient temperature, heating and drying chambers temperatures were also measured with thermometers. This process was repeated each day for a period of one week until desired moisture content is achieved or no further change in weight is observed. Similar method was also adopted to dry the corn and plantain in open sun drying. This was done to compare the quality and quantity of the dried products as well as the drying time. The data from the experiments was used for the calculation of weight loss, moisture content and efficiency of the developed solar dryer.

RESULTS AND DISCUSSION

Details of the results obtained during the performance testing of the developed improved indirect passive solar dryer were recorded. Weight loss, ambient temperature, temperature of the heating chamber and temperature of the drying chamber at an interval of 10 days for both plantain and maize dried in developed solar dryer and open sun drying were noted.

The performance of the developed dryer and open sun drying in term of amount of moisture evaporated were measured at an interval of 9 days and 10 days respectively and are presented in Figure 2 and 3. In both experiments, the maize and plantain lost an average of 0.151kg and 0.29kg over a period of 9 days and 10days. It was observed that the maize and plantain placed in the solar dryer had a faster rate of drying than the maize and plantain placed in the open sun drying due to the fact that the dryer received solar radiation from the heating chamber as well as the drying chamber. The dryer also utilized the stored energy in the absorber when the sun rays were absent. Furthermore, the maize and plantain placed in the open sun drying showed physical degradation, loss of colour and reduction in the

quantity. This was caused by the presence of birds, rodents, rainfall and direct exposure to solar radiation. This agrees with the findings of previous studies [16,17,18].

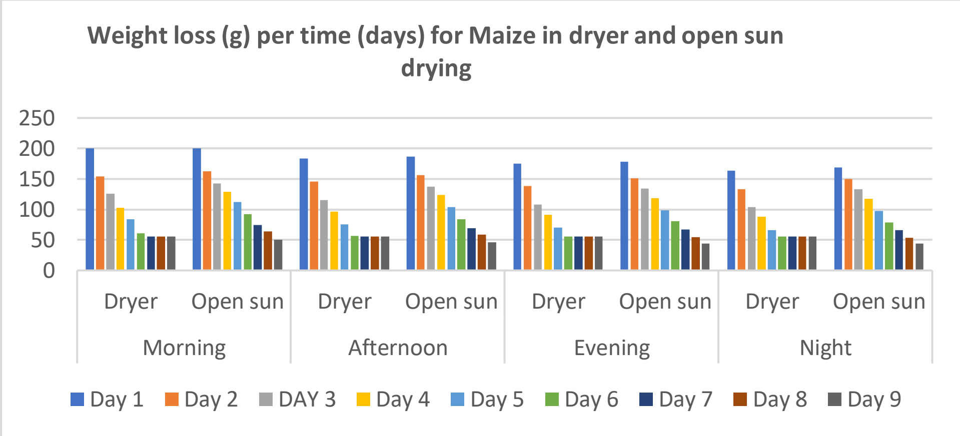

Figure 2: Weight loss against time for maize in solar dryer and open sun drying

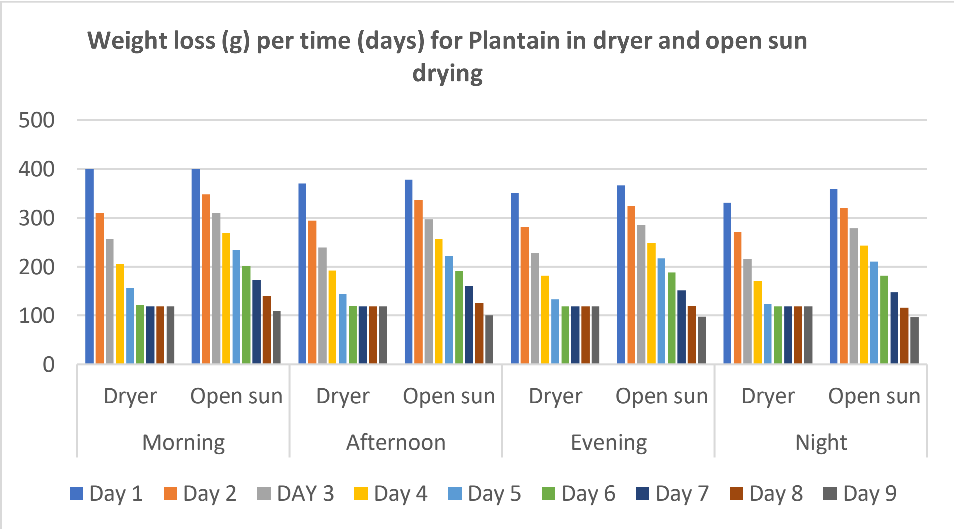

Figure 3: Weight loss against time for Plantain in solar dryer and open sun drying

The effect of ambient temperature was noticed in the drying of the products. In figure 4, in day 1, day 3, and day 6, the ambient temperature went up to 30°C which raises dryer temperature to 38°C and this increases the evaporation of moisture in the product. Moreover, the ambient temperature throughout the experiments was lower than the temperature of the drying chamber. This difference ranged from 1°C to 7 °C as observed by [19,20]. The difference was highest in the afternoon (between 12noon to 3pm) within the range of 2.5°C to 9°C. Between the hours of 8pm to 5am, the difference was between 3°C to 4°C.

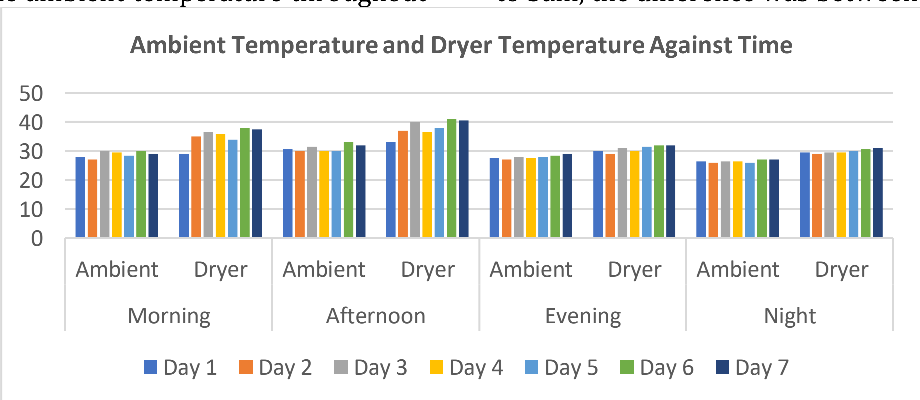

Figure 4: Ambient temperature and drying chamber temperature against time

Moisture content removed and drying efficiency of the developed equipment were compared with that of sun drying technique. The calculations and obtained results are presented.

Moisture content:

$$MC = \frac{Mi - Mf}{Mi} \quad X\ 100 \quad (7)$$

Where;

M_i = Mass of sample before drying
M_f = Mass of sample after drying

For Maize in theOpen Sun Drying:

$$MC = \frac{200 - 55.2}{200} \quad X\ 100$$
$$= \frac{144.8}{200} \quad X\ 100$$

Moisture Content = 72.4%

For Maize in the Dryer:

$$MC = \frac{200 - 44}{200} \quad X\ 100 = \frac{156}{200} \quad X\ 100$$

Moisture Content = 78%

For Plantain in the Open Sun Drying:

$$MC = \frac{400 - 118.5}{400} \quad X\ 100$$
$$= \frac{281.5}{400} \quad X\ 100$$

Moisture Content = 70.4%

For Plantain in theDryer:

$$MC = \frac{400 - 95.2}{400} \quad X\ 100$$
$$= \frac{304.8}{400} \quad X\ 100$$

Moisture Content = 76.2%

Dryer efficiency:

$$\eta = \frac{W.\nabla Hl}{Ac.Ic} \text{ x } 100\% \qquad (8)$$

Where;
η– Drying efficiency

W – Moisture evaporated (kg)

∇Hl – Latent heat of vaporization of water (2320 kJ/kg)

Ic – Hourly insolation upon collector (Wm^2)
Ac – Area of collector (m^2)
For Maize in the Open Sun Drying:

$$\eta = \frac{0.1448 \text{ x } 2320}{0.695 \text{ x } 1897} \text{ x } 100 = \frac{335.936}{1318.415} \text{ x } 100$$

$$\eta = 25.48\%$$

For Plantain in the Open Sun Drying:

$$\eta = \frac{0.2815 \text{ x } 2320}{0.695 \text{ x } 1897} \text{ x } 100 = \frac{653.08}{1318.415} \text{ x } 100$$

$$\eta = 49.54\%$$

For Maize in the Dryer:

$$\eta = \frac{0.156 \text{x } 2320}{0.695 \text{ x } 1897} \text{ x } 100 = \frac{361.92}{1318.415} \text{ x } 100$$

η = 27.45%

For Plantain in the Dryer:

$$\eta = \frac{0.305 \text{x } 2320}{0.695 \text{ x } 1897} \text{ x } 100 = \frac{707.6}{1318.415} \text{ x } 100$$

η = 53.67%

CONCLUSION

An efficient solar dryer has been developed and its drying characteristics have been studied. The developed dryer can be used to dry agricultural products under controlled and protected conditions. The drying system proved efficient and economical for drying agricultural products. The result obtained during the tests reveals that the temperatures inside the drying and heating chambers were much higher than the ambient temperature throughout the experimentation periods. The dryer exhibited sufficient ability to dry food items rapidly to a safe moisture level and ensured a superior quality and quantity of the dried products. The capital cost of the dryer is dependent on the size required for use in application purposes. In this experiment with 200g of fresh corn and 400g of unripe plantain, an overall moisture content of 78% w.b and 76.2% w.b were removed from fresh corn and ripe plantain in the dryer within 7 days. However, 72.4% w.b. and 70.4% w.b. moisture content were removed from fresh corn and ripe plantain placed in open sun drying for 10 days. The efficiency of sun drying was 49.54% for ripe plantain and 25.48% for fresh corn whilst the dryer was 27.45% and 53.67% for fresh corn and ripe plantain respectively. The developed smart solar dryer is economically viable and suggested for the

drying applications among small and marginal farmers in Nigeria.

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